

ECG066

Energy Consumption
Guide

Steam generation costs

The logo for ACTIONenergy. It features the word "ACTION" in a bold, blue, sans-serif font, and "energy" in a green, lowercase, sans-serif font. Above the letter "A" in "ACTION" is a green, six-pointed starburst icon.



This Guide:

- *Gives details on analysis of the results of energy surveys at over 100 sites to show typical thermal efficiencies, factors affecting the thermal efficiency and potential savings*
- *Shows you how to calculate your current thermal efficiency and generation costs, enabling you to compare your performance with that of sites in the energy surveys and gauge your savings potential*
- *Shows actions you can take to improve the efficiency of steam generation and achieve your savings potential.*

Further information on the energy efficient operation of industrial boiler plant is contained in Good Practice Guide 30 and examples of practical applications are found in several Case Studies. "The Essentials" (Industrial Boilers & Heat Distribution Systems-Money to Burn), published under the Action Energy programme, lists all relevant publications and is available from the Action Energy helpline on 0800 58 57 94.

Introduction

Providing steam for process and space heating applications is one of the main energy costs at industrial sites and factories throughout the UK. Steam costs are also a major contributor to energy bills in building complexes within other sectors.

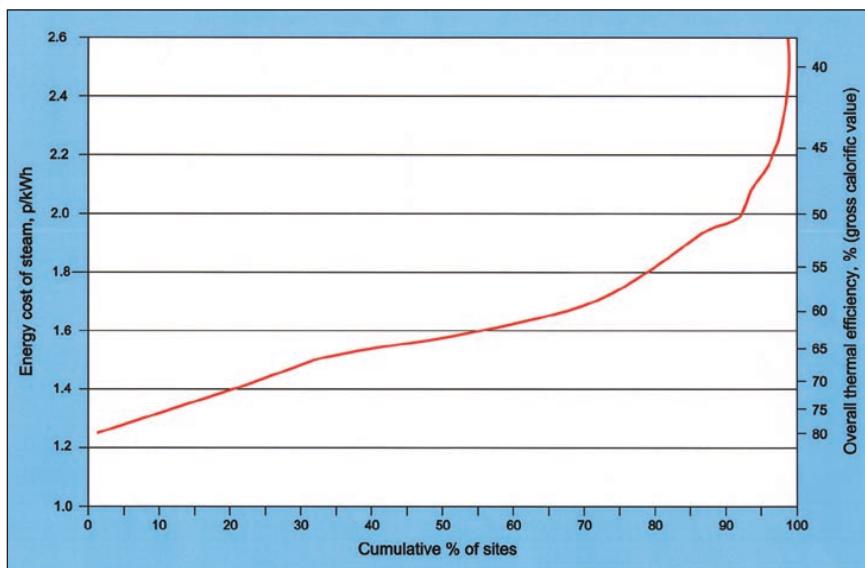
An analysis of steam costs based on energy surveys of 300 boilers was carried out at over 100 sites covering a representative range of industrial, public and commercial users of steam. This shows that the current cost of energy, at the point of use provided by steam is typically 1.6p/kWh (£10.90/tonne) (Figure 1). This cost includes the cost of steam generation and of the energy lost in its distribution.

Eliminating avoidable energy losses associated with steam generation and its distribution (including the return of condensate) could significantly reduce the steam cost at the point of use. The minimum achievable cost is 1.25p/kWh (£8.50/tonne).

This Guide aims to raise awareness of steam generation costs and the potential for cost reduction. The costs and potential savings in steam distribution are dealt with in Energy Consumption Guide 67.

The cost of steam generation is determined by the thermal efficiency of the boilerhouse operation and its operating regime. Analysis of data from the energy surveys on actual energy cost of steam generation at various sites and the potential reduced costs using various energy efficiency measures show that average savings of 7% are possible by improving the efficiency of steam generation, cutting generation costs by 0.1p/kWh of steam energy or 68p/tonne of steam.

Figure 1 Energy cost of steam at point of use (generation and distribution)



Results of the energy surveys

As a result of the energy surveys mentioned, a package of energy saving measures was recommended for each site. Overall savings quoted are based on each site implementing all of the recommended measures.

Thermal efficiency of steam generation

When operated correctly, all modern steam boilers are capable of converting fuel energy input to steam with efficiencies in the region of 80% (based on the gross calorific value of the fuel). Even higher efficiencies are possible if an economiser is fitted. With fuel costs of 1.0p/kWh (29.3p/therm), 80% efficiency would result in steam generation costs of 1.25p/kWh of steam energy or £8.50/tonne of steam generated.

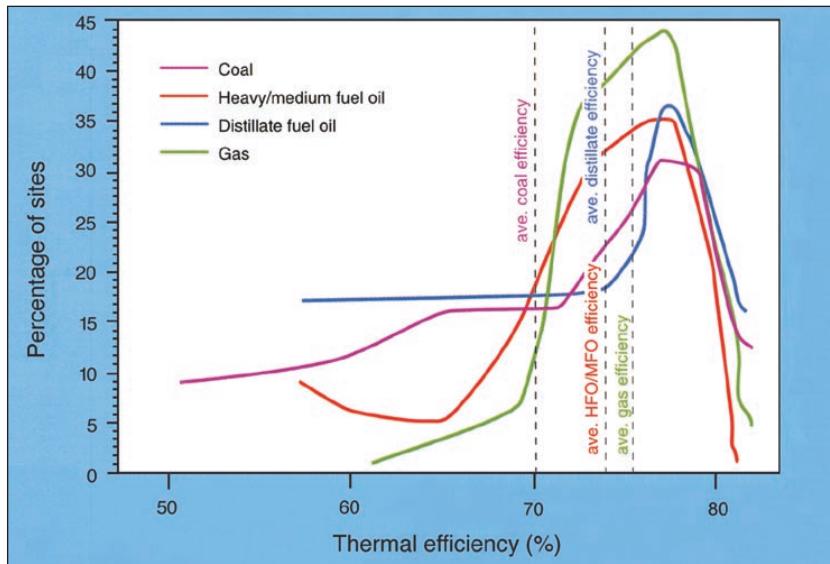
British Standard 845 Part 1 gives a concise test method and calculation procedure for determining the efficiency of a boiler which is operating at a steady load. Although this method is adequate for testing and tuning individual boiler performance, it does not determine the overall performance of the boilerhouse which is more relevant when determining operating costs.

Boilerhouse performance is influenced by many factors, including losses from boiler blowdown use of standby boilers, low-load operation and energy losses within the boilerhouse itself. Comprehensive metering of fuel usage and steam output are needed to give a better indication of the overall thermal efficiency and energy cost of steam generation.

Analysis of boilerhouse data gathered in the energy surveys showed that the average thermal efficiency of steam generation for all fuel types was 74.2%, ranging from 51% to 82% (Figure 2). Boilers operating on gas were found to have the highest average efficiency (76.0%), despite gas having a higher inherent energy loss compared with oil and coal (around 3% on a gross calorific value basis). The high efficiency of gas boilers found in the survey results from various factors, including:

- better turndown
- lower excess air
- cleaner boilers
- newer boiler plant
- the use of economisers.

Figure 2 Steam generation thermal efficiency



Steam generation costs

Table 1 shows the spread of generation costs for steam energy found in the survey, adjusted for all fuels at 1.0 p/kWh.

Table 1 Generation costs for steam energy

	Performance		
	Best	Average	Poorest
Thermal efficiency (% gross)	81.7	74.2	51.0
Steam generation cost (p/kWh)	1.22	1.35	1.96
Steam generation cost (£/tonne)	8.30	9.14	13.33

The cost of steam generation is directly influenced by the price of the fuel used; a price advantage in favour of a particular fuel may well outweigh a relatively smaller thermal efficiency penalty associated with that fuel. Nonetheless, for any particular fuel, significant saving can be achieved by improving thermal efficiency.

Figure 3 shows the cumulative percentage of sites surveyed with actual energy costs at or below the value indicated on the left-hand axis. The cost data presented has been standardised to a fixed fuel unit price of 1.0 p/kWh. For clarity, data for the poorest performing 10% of sites have not been plotted.

Figure 3 Energy cost of steam generation

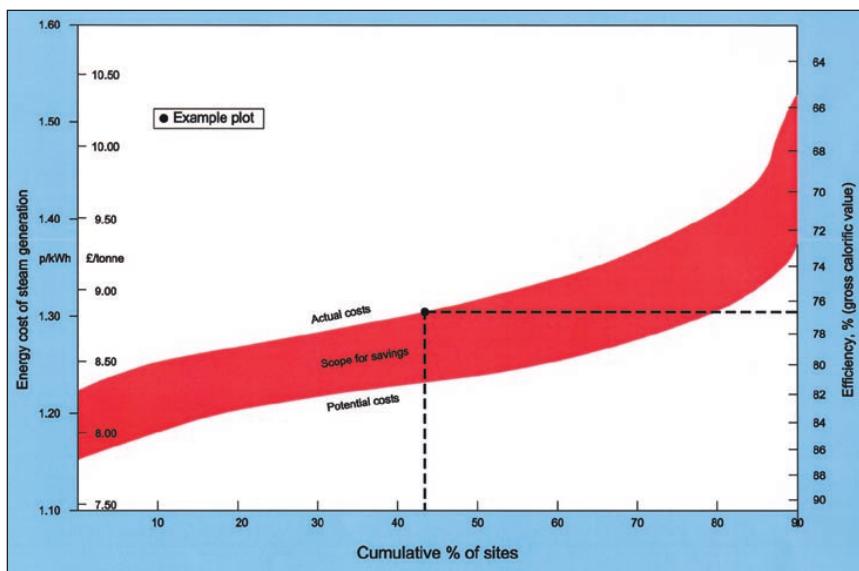


Table 2 Factors affecting steam generation efficiency

Factors reducing thermal efficiency	Factors increasing thermal efficiency
<ul style="list-style-type: none"> • Periods of low-load/no-load • Boilers banked or on hot standby • Short-term load swings. 	<ul style="list-style-type: none"> • Consistent steady loads • Continuous operation.
Penalising: <ul style="list-style-type: none"> • Small sites, which are more likely to have significant seasonal load variations • Sites which operate or are occupied only during daytime • Sites operating a small number of batch processes. 	Favouring: <ul style="list-style-type: none"> • Large production sites operating 24 hours a day • Sites operating continuous processes or large number of batch processes.

Factors influencing steam generation costs

Although much of the observed spread in the standardised steam generation costs in Figure 3 is attributable to non-optimal operation of the boiler, survey results show that the operating regime of the site also affects efficiency and hence costs. The findings are summarised in Table 2.

Small sites with intermittent or variable loads are unlikely to achieve the same level of efficiency as a boilerhouse serving a large, continuously operating process site. Nevertheless there are actions which can be taken to minimise the impact of an operating regime which reduces efficiency (Table 3).

Energy saving potential

At the majority of sites surveyed, a package of measures was recommended to maximize steam generation efficiency. These measures ranged in complexity from simple burner adjustments and improvements to operating procedures, to the replacement of boilers, fuel conversion and the installation of an energy management system. A summary of the measures recommended is given in Table 4.

Potential energy savings for the individual sites ranged from less than 1% to 35%, with an average saving of 7%, worth 0.1p/kWh of steam energy

(68p/tonne of steam generated).

The width of the red band on Figure 3 gives an indication of the savings that are typically achievable, although the savings potential will depend on the particular site. The lower edge of the red band on Figure 3 indicates the distribution of energy costs that would apply if each site implemented all of the identified energy saving measures. The average thermal efficiency would increase from 74.2% to 79.5%.

Table 3 Actions to minimise the impact of an operating regime

Reduce standing losses

- Install flue gas or forced draft fan isolation dampers
- Minimise the use of boilers maintained on hot standby.

Reduce short-term load swings

- Install a steam accumulator
- Schedule production for even loading.

Avoid low-load operation of boilers

- Reduce the number of boilers in operation
- Consider alternative means of providing heat for periods of minimal demand (e.g. immersion heaters).

Table 4 League table of energy saving recommendations

Energy saving measures recommended	No. of sites at which recommendation made
Adjust combustion conditions (burners, air fuel ratio, etc.)	29
Install blowdown heat recovery	20
Install automatic oxygen trim controls	17
Use economisers	17
Use sequential boiler controls (apply only to sites with more than one boiler)	14
Improve operating procedures (apply only to sites with more than one boiler)	10
Install flue gas isolation dampers (apply only to sites with more than one boiler)	7
Replace boiler(s)	7
Carry out boiler maintenance ¹	6
Upgrade boiler controls ²	5
Install automatic total dissolved solids control	5
Improve insulation	4
Recover heat to preheat make-up or boiler feed water	2
Convert boiler fuel (to gas)	2
Total number of recommendations at 77 sites	145

Notes:

¹ Including boiler cleaning, relief valve maintenance, re-tubing and burner replacement.

² Including time switches, modulating control, pressure management, direct digital combustion controls (DDCC) and energy management systems (EMS).

At over a third of the sites, adjustment of combustion conditions (trimming burner air: fuel ratio controls) was recommended, indicating that there is considerable scope for saving energy by minimising excess air levels. The four most frequently recommended retrofit measures, as shown in Table 4, account for over half of the recommendations.



How efficient is your steam generation?



Table 5 Fuel cost multiplying factors

Fuel	Multiplying factor to give steam cost with fuel at 1.0p/kWh
Natural	gas 29.31/ (your cost of fuel in p/therm)
HFO	11.65/ (actual cost in p/litre)
Gas oil	10.58/ (actual cost in p/litre)
Coal	77.53/ (actual cost in £/tonne)

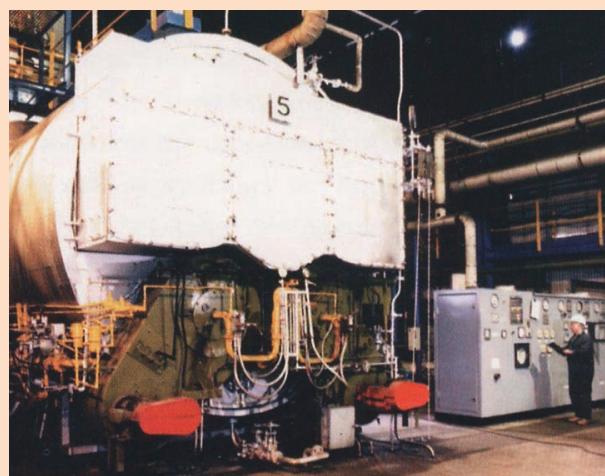
Table 6 Fuel gross calorific values (typical)

Fuel	c.v. in BTU	c.v. in MJ	c.v. in kWh
Natural gas	1,040 Btu/ft ³	38.75 MJ/m ³	10.76 kWh/m ³
HFO (S.Gr. 0.98)	18,400 Btu/lb	42.80 MJ/kg	11.65 kWh/litre
Gas oil (S.GR. 0.84)	9,500 Btu/lb	45.36 MJ/kg	10.58 kWh/litre
Coal (as fired)	12,000 Btu/lb	27.91 MJ/kg	7,753 kWh/tonne

To compare your steam generation efficiency and steam energy costs with those sites in the energy survey, as shown in Figure 3, you should use one of the two steam calculators, depending on the information you have available.

The first, steam energy cost calculator, shows you how to calculate your steam energy cost, taking you through the necessary steps to adjust your actual fuel costs to the equivalent cost at 1.0p/kWh – you will need the information in Table 5 for this.

The second, steam generation efficiency calculator, shows you how to calculate your thermal efficiency – this requires a knowledge of fuel calorific value (Table 6) and heat absorption data (available in steam tables). In each case, a worked example is provided to clarify the procedure. The example is based on a site which burns 3.8 million litres of Heavy Fuel Oil (HFO) per year to generate 50,000 tonnes of steam at 10 bar(g) from boiler feed water at 80°C. The average price of HFO at the site is 12.5 p/litre.



Cost and efficiency calculators

Method 1 Steam energy costs calculator

Step	Your steam energy costs	Example steam energy costs
Fuel used per year (A)	_____ litres HFO _____ therm Gas _____ litres Gas oil _____ tonnes Coal	3,800,000 litres HFO
Actual unit cost for fuel (B)	£ _____ / _____ (litre/therm/tonne)	£0.125/litre
Annual fuel cost = (A) x (B) (C)	£ _____	£475,000
Steam generated per year (D)	_____ tonnes	50,000 tonnes
Cost per tonne of steam = (C) ÷ (D) (E)	_____ £/tonne	£9.50/tonne
Cost of steam if fuel unit cost 0.6 p/kWh (F) = (E) x Multiplying factor from Table 5	_____ x _____ = _____ £/tonne	9.5 x <u>11.65</u> = £8.85/tonne 12.5
Standardised cost of steam in p/kWh (G) = (F) ÷ 6.78	_____ p/kWh	1.305 p/kWh
Average thermal efficiency = standard unit fuel cost in p/kWh ÷ (G) x 100	_____ %	$\frac{1.0 \times 100}{1.305} = 76.6\%$

Plot the value of (G) on Figure 3 to see how your steam energy costs compare with those at the sites surveyed. The example results are plotted on Figure 3 and show that 42% of sites produce steam energy at a lower cost.

Method 2 Steam generation efficiency calculator

Step	Your steam energy costs	Example steam generation efficiency
Steam pressure (A)	_____ bar (g)	10 bar (g)
Specific enthalpy of steam at pressure (from steam tables) (B)	_____ kJ/kg	2,781 kJ/kg
Boiler feed water temperature (C)	_____ °C	80°C
Specific enthalpy of feed water (from steam tables) (D)	_____ kJ/kg	335 kJ/kg
Heat absorbed per kg of steam generated = (A) – (B) (E)	_____ kJ/kg	2,446 kJ/kg
Steam generated per year (F)	_____ tonnes	50,000 tonnes
Annual heat absorption in GJ/year = (C) x (D) x 10^{-6} (G)	_____ GJ/year	122,300 GJ/year
Annual heat absorption in MWh/year = (E) ÷ 3.6 (H)	_____ MWh/year	33,972 MWh/year
Annual fuel use (I)	_____ litres HFO _____ therm Gas _____ litres Gas oil _____ tonne Coal	3,800,000 litres HFO
Annual fuel heat release in MWh = (G) x gross calorific value of fuel in kWh x 10^{-3} (J)	_____ x _____ $\times 10^{-3}$ = _____ MWh/year	$3,800,000 \times 11.65 \times 10^{-3}$ = 44,270 MWh/year
Average thermal efficiency = ((F) ÷ (H)) x 100 (K)	_____ %	$\frac{33,972}{44,270} \times 100 = 76.7\%$

Plot the value of (K) on Figure 3 to see how your steam generation efficiency compare with those at the sites surveyed. The example results are plotted on Figure 3 and show that 43% of sites are more efficient.

What could you be saving?

Plot the result from the steam calculator on Figure 3 and see what your savings potential is, based on the savings possible at the sites surveyed.

The example results, plotted on Figure 3, suggest that the energy cost of steam generation could be reduced from 1.305 p/kWh (£8.85/tonne) to 1.228 p/kWh (£8.33/tonne) for a fuel price of 1.0 p/kWh. This saving of 6.0% would be worth £28,500 p.a. based on the current annual fuel bill of £475,000.

How to achieve your energy saving potential

This section suggests actions you can take to achieve your energy saving potential. Many of the following measures are discussed more fully in Good Practice Guide (GPG) 30 (Energy efficient operation of industrial boiler plant) and GPG18 (Steam metering).

Optimise combustion conditioners

- Check combustion conditions regularly, or monitor and control them automatically
- Aim to minimise flue gas oxygen (excess air) without producing excessive levels of carbon monoxide or a smoky stack. The burner manufacturer will advise on the optimum levels of excess air and carbon monoxide over the turndown range of the burner.

Note: Adjustments to burners or combustion controls must only be undertaken by a competent, suitably qualified person. A badly adjusted burner wastes fuel and is a potential explosion hazard.

A 2% reduction in flue gas oxygen will give a fuel saving of 1.2%.

Install oxygen trim control or Direct Digital Combustion Control (DDCC)

These measures can often be justified on the basis energy savings achieved by the continuous optimisation of excess air. See GPCS338 – Improving efficiency by renewing boiler burners and controls.

Install blowdown heat recovery

Typically, for boilers with deionised (softened) make-up water, between 1% and 5% of the energy input to the boiler is lost in blowdown.

- Recover flash steam from blowdown – it can be used to heat the hot well or deaerator
- Recover residual heat from blowdown – it can be used to heat the treated make-up water.

Flash steam recovery can reduce blowdown energy losses by 50%, giving a typical fuel saving of 0.5-2.5%. Heat recovery from the residual blowdown water can reduce the losses by a further 25%, giving an overall fuel saving of 0.75-3.75%. See GPCS339 – Heat recovery from boiler blowdown.

Use economisers

Use heat from the boiler flue gases to pre-heat the incoming boiler feedwater.

Note: Heat recovery is limited by acid dew point considerations, i.e. economiser and chimney corrosion, and acid smutting.

Every 20°C reduction in flue gas temperature will give fuel savings of 1.25%, yielding typical saving of 3-8% or more with a condensing economiser on a gas fired steam boiler.

Improve operating procedures and sequential boiler controls

- Reduce standing losses and losses associated with operating at low loads
- Use sequential switching on/off of boilers in response to load
- Eliminate boilers on hot standby at full pressure
- Minimise the number of boilers in service.

Improvements to the operating regime can give fuel savings of up to 5%. See GPCS352 – Improved Turndown and Fuel Savings on a Coal-Fired Boiler.

Install flue gas isolation dampers

Reduce standing losses by preventing air being drawn through the boiler when it is not firing. Alternatively, fit an isolation damper on the air inlet to the combustion air fan.

Fitting isolation dampers can produce fuel savings of over 1%.



For further information please contact:
Action Energy helpline
Tel **0800 58 57 94**
www.actionenergy.org.uk

Tel **0800 58 57 94**

www.actionenergy.org.uk

Action Energy is a programme run by Carbon Trust and funded by the Department for Environment, Food and Rural Affairs, the Scottish Executive, Invest Northern Ireland and the National Assembly for Wales.

Whilst we have taken reasonable steps to ensure that the information contained within this Guide is correct, we give no warranty and make no representation as to its accuracy and we accept no liability for any errors or omissions and nor does Carbon Trust nor the Government.

Action Energy is a Carbon Trust programme. Carbon Trust is a company limited by guarantee. Registered in England and Wales Number 4190230. Registered at: 9th Floor, 3 Clement's Inn, London WC2A 2AZ.